"OK, Google. Find me the Squidly Island DXpedition on 20 meters ... and let me know when you've made the contact." Is this a snapshot from ham radio's future? WB2REM and K5PA say the technology for it is on the horizon. And some elements of artificial intelligence can be used in our ham shacks today.

AI Meets AR

The Coming Convergence of Artificial Intelligence and Amateur Radio

BY JIM MILLNER,* WB2REM AND GENE HINKLE,# K5PA

Artificial intelligence (AI) has permeated all aspects of our lives. We use AI devices to control lights, provide answers to questions, and instantaneously calculate math. So, why not use AI to enhance the amateur radio operating experience? This article provides proof of concept examples of how Amazon Alexa, Google Home Mini, Ultra Hal 7, and their variants can be used to accomplish this goal. Lastly, the future of AI in amateur radio (*Photo A*?) will be discussed.

In everyday life, we are increasingly using artificial intelligence in our homes. These devices rely on cloud databases of data, which, when accessed, provide information and perform desired tasks. On a higher level of artificial intelligence, sometimes called "true or strong" intelligence, the AI software can show behavior and skills that are like human capabilities and provide near-conversational skills, like Hal in *2001: A Space Odyssey*. In this article, we will touch on both areas of AI and their potential uses in ham radio.

Photo A. Artist's concept of an AI amateur radio operator. (WB2REM commissioned drawing)

AI Hardware — Google Home Mini (Modified)

One of the biggest obstacles to integrating AI devices, such as Alexa and Google Home Mini, into ham radio stations has been the ability to bring audio into and out of AI devices through built-in jacks. Extensive research on the subject led us to a company in Toronto, Ontario, called Snektek.[1] This company has developed a proprietary printed circuit board assembly, or PCBA[2] (*Photo B*), which, when installed inside a Google Home Mini, gives speaker-output and microphone-input connections. Snektek sells the mod as a kit for $150 as well as a completed unit (*Photo C*) for $350.[3]

A cable from the front microphone audio input and ground from the 8-pin round Foster connector was connected through a ground loop isolator into the audio output of the modified Google Home Mini (*Figure 1*). The microphone connection may need a small capacitor added to block the bias voltage from the mic circuit connection to the ground loop isolator, depending on the isolator selected (see Note 1, DC Block, on the schematic). To bring audio into the Google Home Mini, a custom-made stereo cable connected to the rear speaker output of an ICOM IC-7600 (using the tip and sleeve) was connected through a ground loop isolator to the Mini's input (using the ring and sleeve).

VOX was used to allow the Google Mini's audio to be transmitted. Initially, the squelch of the radio was placed at the threshold of the radio to reduce static, which could interfere with over-the-air Google commands. The monitor of the radio should be turned on and adjusted so the Google Home Mini can hear your voice and respond to your commands when you talk on the radio's microphone. The receive volume of the transceiver should be carefully adjusted by using an over-the-air station to speak the Google Mini wake up command, such as "OK Google, what's the weather?" This is critical because too

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much or too little volume will not be decoded by the Google Mini. Make sure to also adjust the output volume of the Mini. This can be done by telling it to raise or lower its volume by a certain percentage and / or change the transceiver microphone gain for best-sounding transmitted audio.

To make this more amateur radio friendly, a program called IFTTT (If This Then That)[4] was used to program specific commands. We used the IFTTT app, which can be downloaded for free on an Android phone or iPhone. IFTTT allows the programming of responses that are triggered by verbal commands. For example, IFTTT was programmed to respond to the callsign WW1WW in the following manner: When "Hey Google, WW1WW" was said on the air, the Google Home Mini responded, "Good morning Woody, you are 5 by 9 as usual. Hope you are having a good day; this is WB2REM." Commands related to "What is your rig?" "What is your location?" and "Call CQ" are examples of what you could program. There are numerous articles on the web that go through the step-by-step process of setting up IFTTT commands.

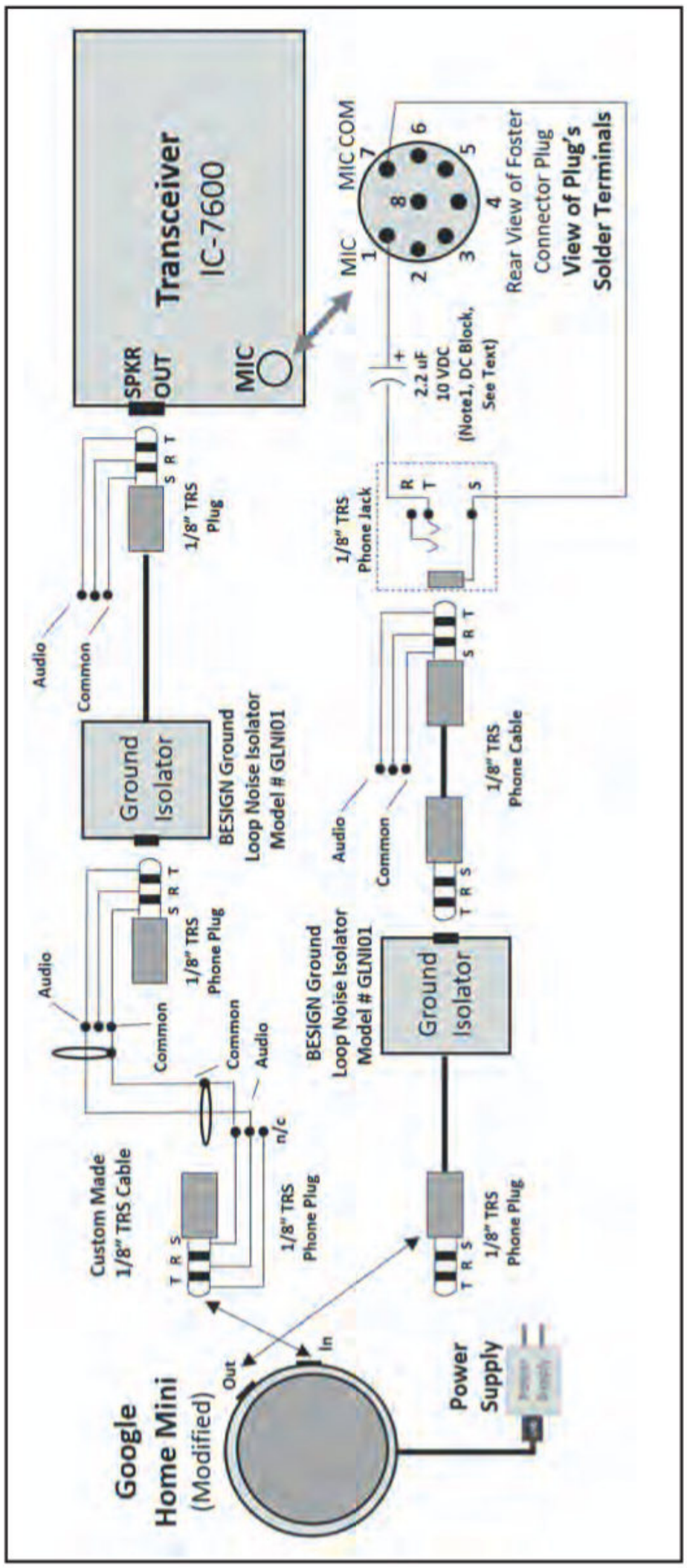

Figure 1. Modified Google Home Mini (see text). (K5PA drawing)

AI Hardware — Acoustic Google Home Mini

A less expensive solution is to use an unmodified Google Home Mini. We call this approach "Google in-a-Box." We purchased a lapel microphone (*Photo D*)[5], a pillow speaker (*Photo E*)[6] and connected them to the microphone and speaker output of the 7600 (*Figure 2*). The lapel microphone and speaker were placed with the Google Mini in a Pelican "style" soundproof case with a hole drilled in the back to pass the wires (*Photo F*).[7] The Google in-a-Box setup worked well as a cheaper alternative to Snektek's modification. The only

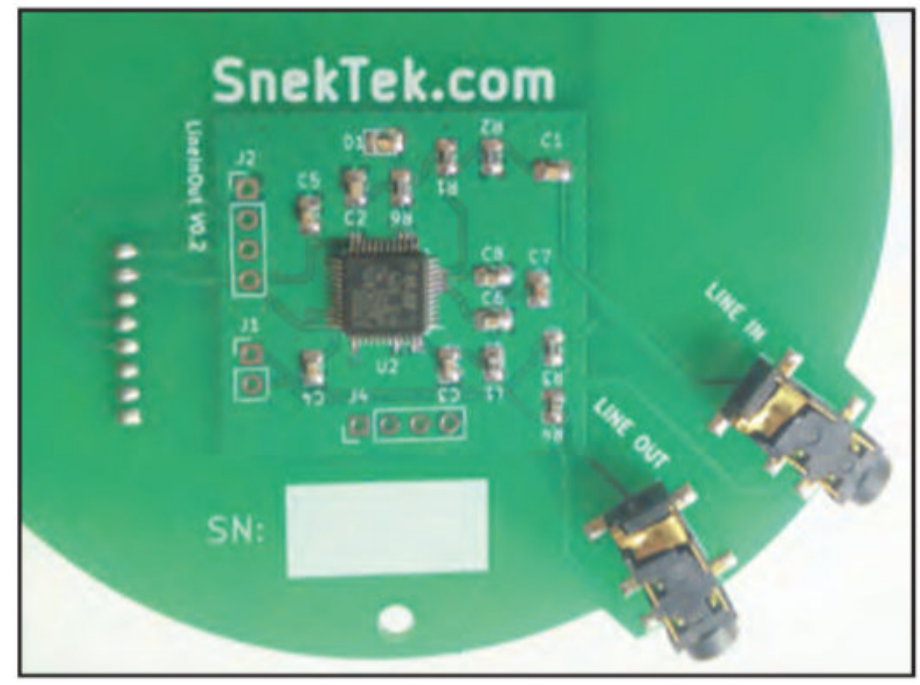

Photo B. SnekTek's Google Home Mini Mod Kit. (SnekTek website photo)

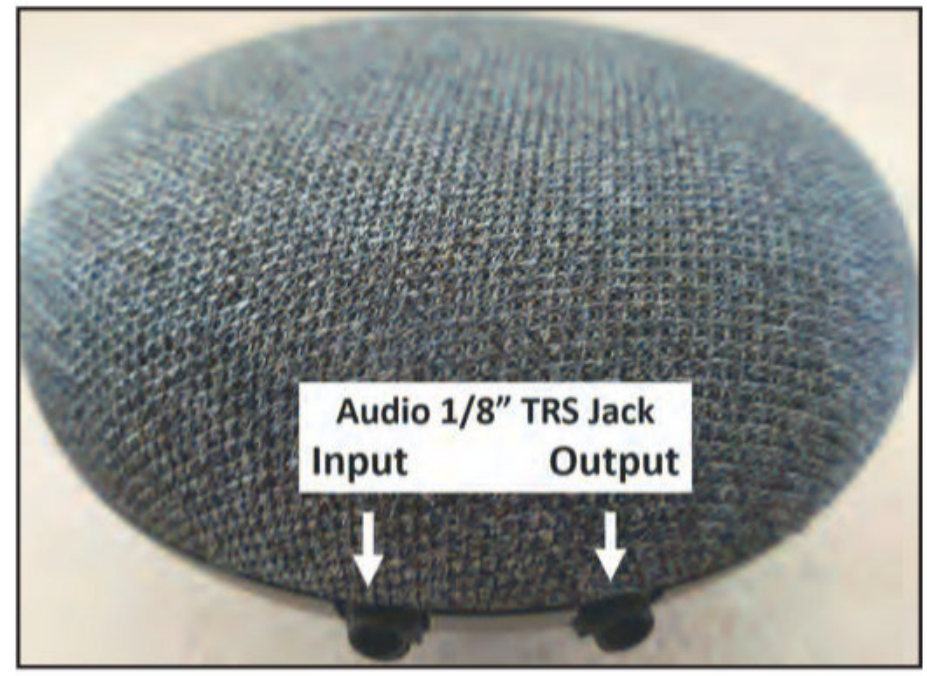

Photo C. Google Home Mini with mod kit installed. (WB2REM photo)

issue we experienced was a hollow type of transmitted audio effect, possibly caused by the acoustics of the box. When we opened the box, the audio cleared up. This is an area for further exploration.

The Google Home Mini AI introduction into ham radio was quite successful. The benefits of using it include its ability to answer sequential questions after saying "OK Google" (if it is within 7 seconds), the ability to access Google's search engine, and its responsiveness to IFTTT skills. As a side note, weak signals, QRM and the clarity of the over-the-air operator voices can produce incorrect responses or no response at all. As with the Google Home Mini and other approaches, it is imperative and legally necessary to be in control of your station and have an audio kill-switch built into the system when unwanted responses inadvertently occur.

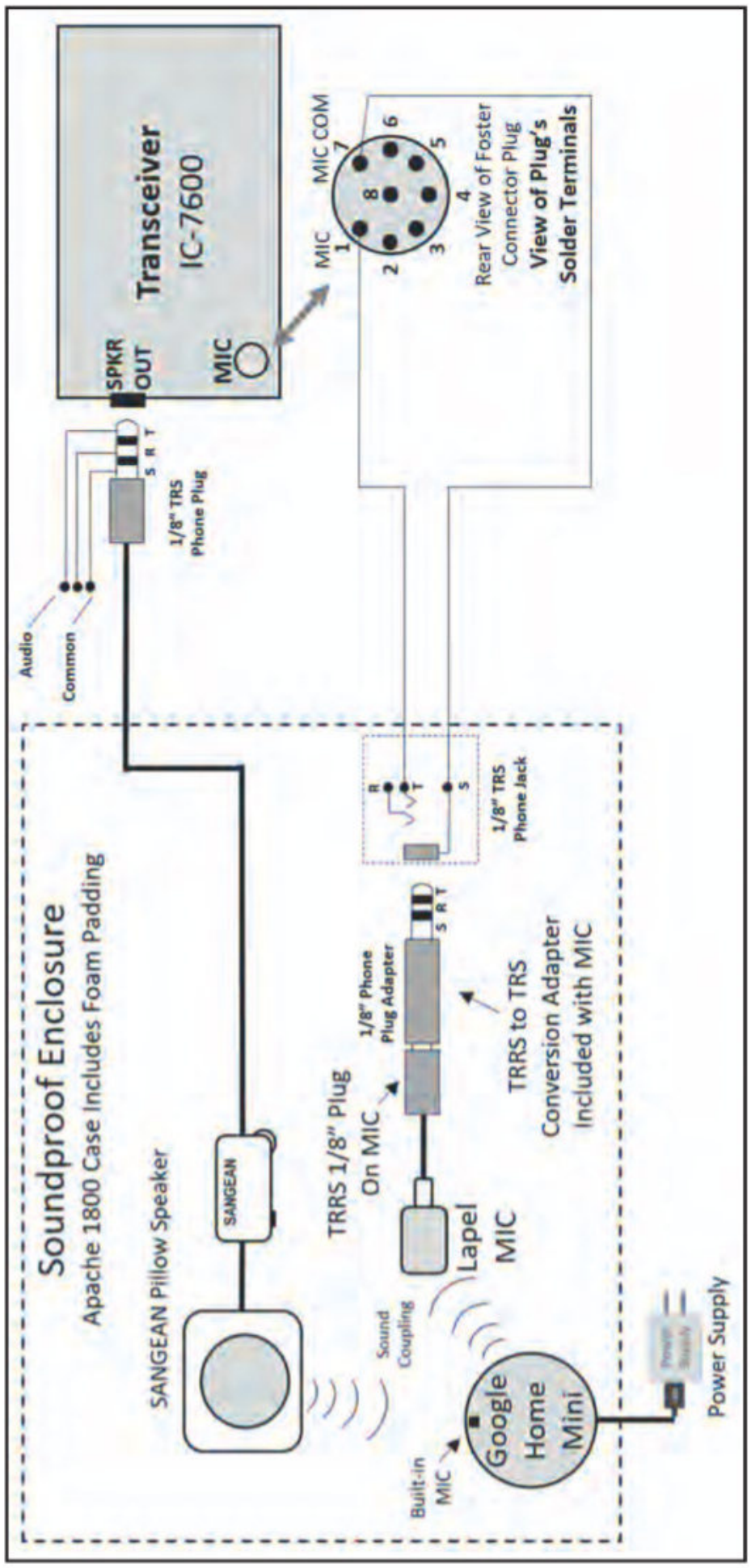

Figure 2. Google Home Mini in-a-Box. (K5PA drawing)

AI Hardware — Amazon Alexa Echo Dot

Next, we tried the Amazon Alexa Echo Dot (3rd Gen.)[8] (*Photo G*). The Echo Dot functions like the Google Home Mini in its ability to retrieve information. One shortfall was that the Alexa Echo Dot did not have an audio input jack (nor does any Alexa model). The Echo Dot does have an audio output jack, which can be used to send audio from the Dot to the radio's microphone through a ground loop isolator. *Figure 3* shows the connections between the Alexa Echo Dot and the transceiver.

To solve this problem, the Sangean Portable pillow speaker, as mentioned with the "Google in-a-Box," or something similar, was used to bring audio from the radio's speaker out

Photo D. Lapel microphone (WB2REM photo)

Photo E. Sangean pillow speaker (WB2REM photo)

to the Alexa Dot's internal microphone. We placed the Alexa Dot in a moderately soundproof box, like "Google in-a-Box," and placed the speaker in the case with the Echo Dot. Although this approach was not ideal, proof of concept was obtained. Audio out from the Alexa can be adjusted by using the +/- buttons on the top of the Alexa. One downfall to Alexa Echo Dot is how it interacts with IFTTT. The IFTTT commands do not produce a verbal response as with the Google Home Mini, thus making IFTTT useless with this device. As with the Google Home Mini, information can be requested, and responses broadcast through an "Alexa" command. However, "Alexa" needs to be said before each command to get her attention.

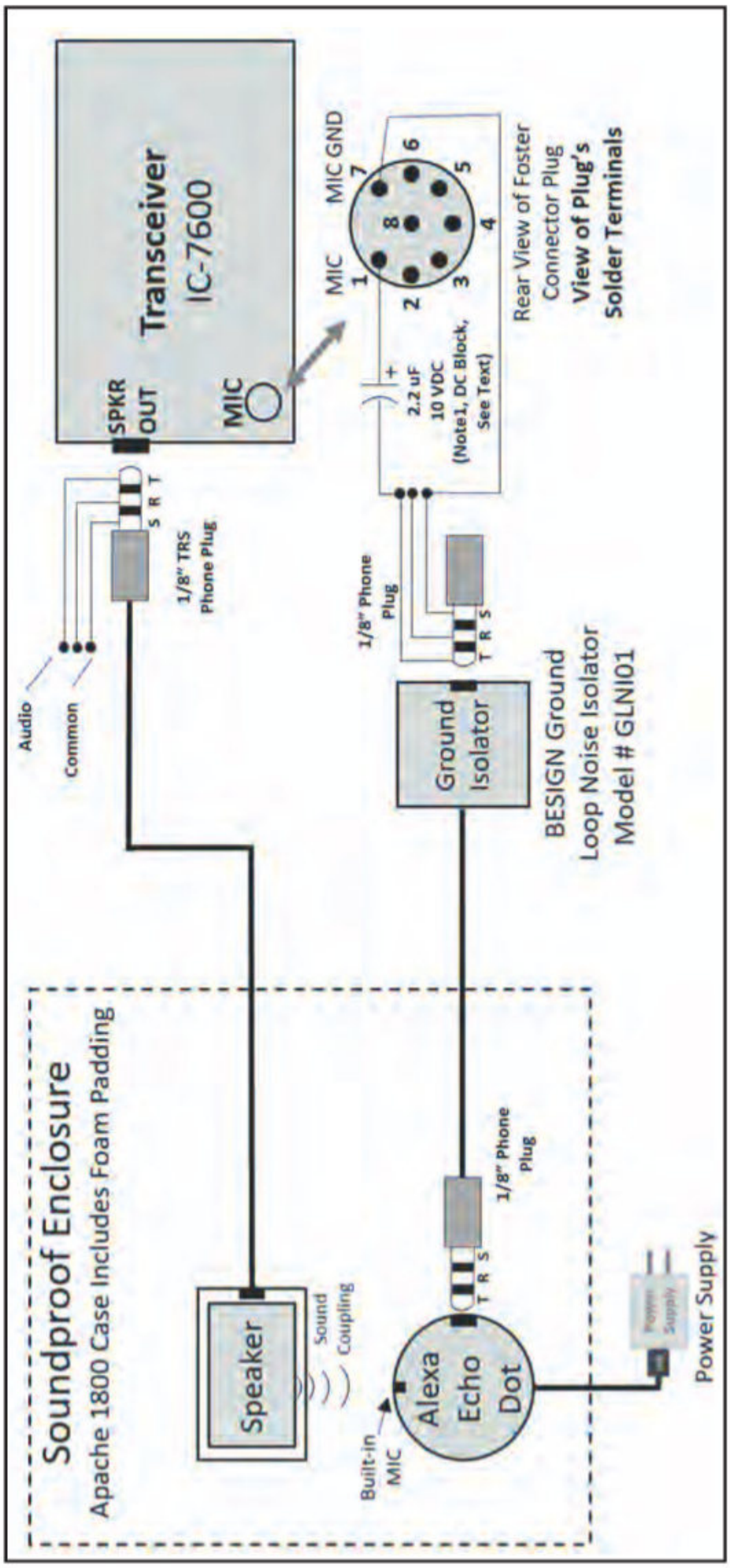

Figure 3. Alexa Echo Dot in-a-Box. (K5PA drawing)

Software-Based Solutions — Alexa

There were two approaches to using software. The first and easiest method was to download Amazon Alexa Windows software. Once the Alexa software is installed on a Windows 10 computer, it will be necessary to provide audio from the speaker output of the radio through a ground loop isolator to the microphone input of the computer, and from the speaker out of the computer through another isolator into the microphone input of the radio (see *Figure 4*). The microphone and speaker-out levels on both need to be carefully set, so the VOX on the radio is not falsely tripped. There is also a setting in the Alexa Windows software in which a VOX-type system can be employed. This method is not foolproof and requires careful monitoring. Overall, this method did not work well. Sometimes, the audio from the computer would not trip the radio's VOX and likewise, Alexa would not hear its command when static was present.

Software-Based Solutions — Ultra Hal 7

Ultra Hal 7 is true AI interactive Windows software developed by Zabaware. Its human-like verbally responsive nature is truly impressive. Out of the box, Ultra Hal 7 relies on an already-established online database brain, which helps it to interact with the user (*Photo H*).

As it is trained through conversations with the users, it stores unique conversation aspects and when questions are asked in the future, it becomes more responsive to those types of questions. Ultra Hal 7 comes much closer to "true" intelligence than any of the other devices listed above. As with Alexa software, microphone and speaker audio to and

Photo F. Enclosure (Harbor Freight website photo)

from the radio are connected to the computer. There is no need to say, "OK Google" or "Hey Alexa," for it is pure conversation. The name I gave for the user is "ham friend." When you say, for example, "Good Morning," it might respond, "Good Morning ham friend and how is your Monday going?" It has a wide range of answers to questions and remembers what was said in the past. It is truly amazing. It has been tested over-the-air with some success, but noise and static can negatively affect its ability to correctly respond. The program costs $29.95 with additional minor costs for add-ons for specialized voices.

Table 1 provides a comparison of the different technologies tested. In summary, the Google Home Mini with the input and output jacks worked the best. Its ability to access the vast Google search lookup, respond to sequential questions without saying "OK Google" each time, and its use of IFTTT skills currently make it the best AI to use on amateur radio. Alexa, with its output jack and audio acoustically fed to a microphone, takes second place. Google Home Mini without internal connections worked well but needed fine adjustment to clarify the audio. Lastly, Ultra Hal 7, which might work best in theory, requires extensive training and future advancement to be ham radio friendly. For future testing, these devices and software may work better in a noise-free environment, such as on a repeater. Further testing in this area is needed.

The Future of Artificial Intelligence in Amateur Radio

We divide the future of AI in AR into current, medium-, and long-term timeframes. This is convenient since it is the technology that drives the capabilities that can be applied to our hobby. However, advances must be made in several different arenas for AI to flourish. These include underlying technology, regulatory, and organizational changes. We all know the pace at which technology drives our desire for faster and better devices. These are evident, looking at computer technology, cellphone advancement, and now AI applications for the consumer. These advances bleed over the technology into other facets of our lives, including amateur radio.

Current Status — AI in the Home and on the Phone

We define the current status as consumer use of AI to perform personal tasks in the home and on our cellphones. Personal assistants, such as Siri, captured the imagination of how AI could be mobilized to every smartphone. This led to personal assistants in the home typified by Alexa, Google Home, and others. These advances are now commonplace in our homes and in our ham shack. There are no barriers to using personal assistance with our ham radios to gather information that's helpful to our daily on-the-air activities. We include asking for the time, geographical information, local or world weath-

Photo G. Alexa Dot (WB2REM photo)

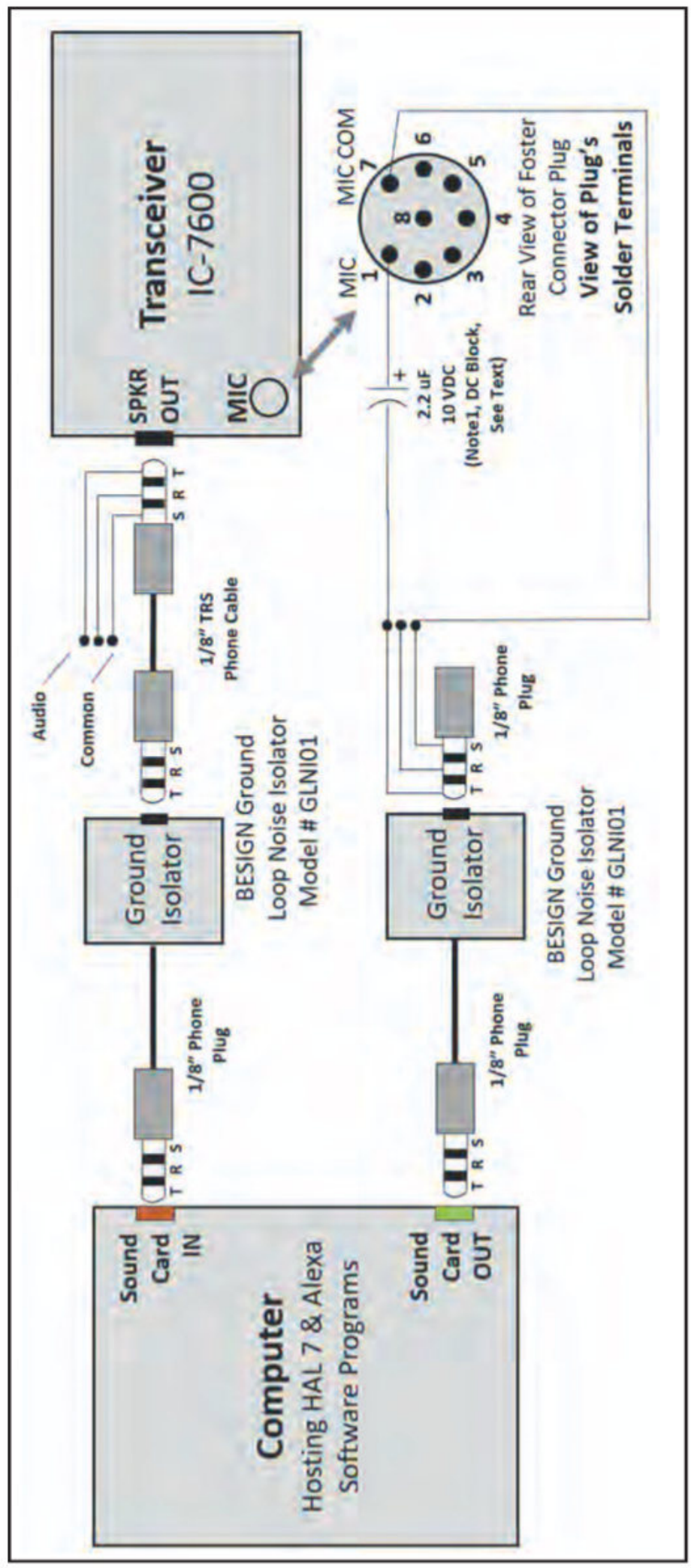

Figure 4. Ultra HAL 7 & Alexa Software to Radio Interface. (K5PA drawing)

Photo H. Ultra Hal 7 Graphical User Interface (GUI). (WB2REM screen capture)

er, and other information useful for real-time assistance during QSOs.

Medium Term — On-the-Air Assistance Manager

With advances in technology and greater acceptance, we expect AI will find applications with radio control, verbal queuing, logging, and QSO exchanges. Currently, AI is being applied to consumer applications due to the large marketplace. Niche markets such as amateur radio are different domains in which knowledge needs to be specifically applied through rules-based system algorithms like IFTTT, and information databases need to be tailored for the application. With greater usage, we expect the knowledge base to extend to a larger population.

Radio control can be as simple as verbal commands to set up radio communications, including all equipment and interconnects. More complex reasoning would be finding a clear frequency based on propagation characteristics between points on the Earth and measuring the availability of clear spectrum at each end of a link. At the time of this writing, the Defense Advanced Research Projects Agency (DARPA) is already holding industry competitions (with financial rewards) to use AI to achieve greater efficiency of the available cellphone spectrum for data and voice. The fruits of this technology could be applied to our niche in time.

Long-Term — "AI Associates" Integrated Into Station Operation

Perhaps the most controversial aspect of AI and one that extends into the heart of amateur radio is the "AI Associate" (not Assistant) that complements the human operator in station operation and control. Think robotic interaction with our radio systems. We have all heard the arguments before that such technology is not ham radio; so it will be with the AI Associate concept. But our purpose here is to discuss the technology. We'll leave discussion of its appropriate uses to another time and forum.

We are considering a time when the ham population may be shrinking, and we may be trying to hold onto spectrum for amateur use. With fewer amateurs, it might seem realistic to expect an AI Client to be a component of an Associate in our ham shacks. Does this seem far-fetched? We believe that many of the components are already around us today.

The capability of AI to recognize callsigns, provide information to the control operator (you), and measure signal-to-noise ratio of a signal to report would allow the AI Associate to speak, send data, or communicate with the QSO partner. We believe this is not only possible but probable in the 5- to 10-year timeframe. What will be unique is the ability to have this occur on both ends of the communication link, e.g., AI Associate-to-AI Associate.

At first, the control operator (you) will be monitoring the communications to abide by all regulatory requirements in real time. Looking ahead, though, AI monitoring could be allowed by national regulatory agencies and / or worldwide bodies. Who will be the first to accomplish this feat?

AI Issues and Amateur Radio

In our discussion of AI and amateur radio, we have touched on several issues. Some of the key ones are regulatory issues with agencies and gov-

TABLE 1. AI Comparisons

Device/Software	Price Class	Access Search Engines	Uses IFTTT Skills	Responds to Sequential Commands	Phone Patching	Turn On Switches/ Lights
Google Home Mini (Modified)	$350	Yes	Yes	Yes	Yes	Yes
Amazon Alexa in a Box	$50	Yes	Yes, but only written response	No	Yes	Yes
Google Home Mini (No Jacks)	$35	Yes	Yes	Yes	Yes	Yes
Amazon Alexa Software	$0	Yes	Yes, but only only written response	No	Yes	Yes
ULTRA HAL 7	$30	Yes, but no verball response	No	Near true AI speech	No	No

TABLE 2. IS AI IN THE FUTURE OF AR?

Function	Complexity	Timeline	Regulatory	Organizational	Tethered
Personal Assistant	Domain knowledge	Now	No	No	Yes
OTA Assistance	Domain Knowledge	Now	No	No	Yes
Radio Control	Medium	5-10 years	No	No	No
Verbal Que Assistance	Speech Recognition	5-10 years	No	No	
Radio Control	Speech Recognition	5-10 years	No	No	No
Logging	Speech Recognition	5-10 years	No	No	No
QSO Exchanges	Speech Recognition, Radio Control	Medium Term	Control Op Requirement	Rules Changes Needed	Yes, but not preferred
Remote Site Monitoring	Autonomous Versus Monitored	5-10 years	No	No	Yes
2-way QSO	Merging of AI, Control, and Regulation	10-20 years	Control Op Requirement? Maybe!	Rules Changes Needed	2-way QSO

ernments that are slow to adapt via new regulations. Some of the early concepts do not require any regulation changes. However, we are almost guaranteed that the technology will be ahead of any governing body.

Another issue is the non-governmental rules changes that will be necessary for wider acceptance of AI. Here, we are thinking that the rules committees for awards and contests would have to get in step with AI in the ham shack. Imagine an AI Associate that you are monitoring is operating the radio, selecting QSOs and transmitting the messages needed for awards or contests. Would this be allowed by the committees? In time, the ham radio population will demand it if this is part of our future. Otherwise, new awards will be defined under the AI Associate concept. A rhetorical question is, "When will there be an AI Associate-to-AI Associate QSO logged without a control operator present?"

Another key issue is the concept of AI tethering. We talk in terms of the AI client being connected back "to the mothership," meaning that the AI information databases and complex reasoning resides on large server farms connected over the internet. The internet is the tether of the information. It is desirable at times to not require a remote tethering to the information but rather have it local to the radio or even "inside" the radio. For example, autonomous spectrum monitoring and frequency selection might be performed by an AI processor module embedded in the transceiver.

Summary

As mentioned throughout this article, the purpose of this project is to prove concept on how artificial intelligence (AI) can be used in ham radio. As AI advances, so will the ability to integrate it into your radio shack. Eventually, you will be able to verbally ask the radio to turn on, search for stations or call CQ. It could be trained to recognize its own callsign, respond to stations by giving a signal report and location information while the control operator is present to log the contact. Is this our future? It may well be. However, in the end, nothing will take the place of true human-to-human interaction.

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